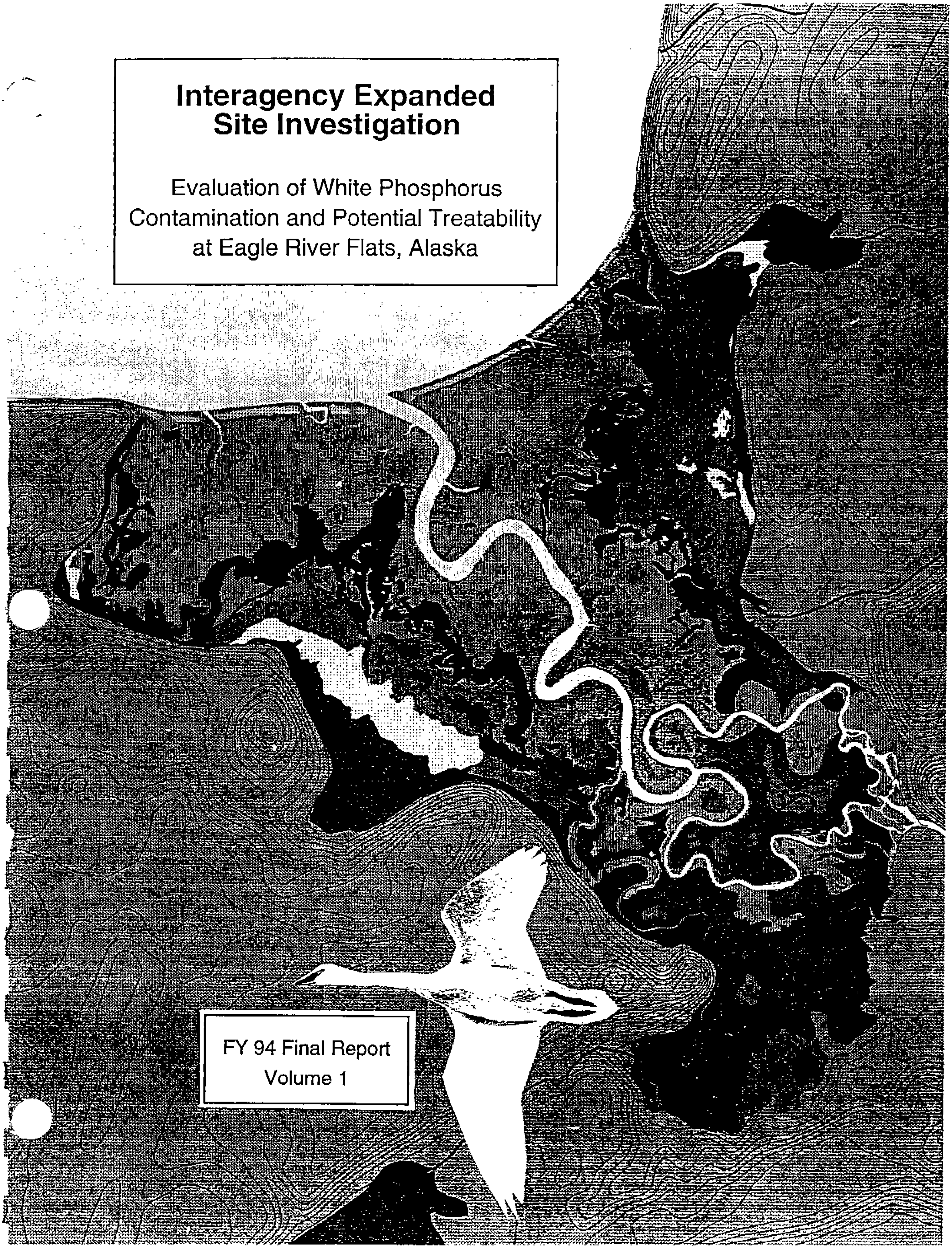
Interagency Expanded Site Investigation

Evaluation of White Phosphorus Contamination and Potential Treatability at Eagle River Flats, Alaska



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INTERAGENCY EXPANDED SITE INVESTIGATION: EVALUATION OF WHITE PHOSPHORUS CONTAMINATION AND POTENTIAL TREATABILITY AT EAGLE RIVER FLATS, ALASKA

FY94 FINAL REPORT

Prepared for

U.S. ARMY, ALASKA
DIRECTORATE OF PUBLIC WORKS
William A. Gossweiler
Project Manager

Prepared by

U.S. ARMY COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
Charles H. Racine and David Cate, Report Editors

CONTRIBUTORS

C. Racine, M.E. Walsh, C. Collins, D. Lawson, S. Bigl, B. Nadeau, L. Hunter, J. Bodette, E. Chacho, R. Haugen, K. Henry, M.R. Walsh, E. Chamberlain, D. Garfield, P. Weyrick, M. Brouillette
U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH

C. Bouwkamp
U.S. Army Environmental Hygiene Agency, Aberdeen Proving Grounds, MD

J. Cummings, L. Clark, J. Davis, P. Pochop, C. Yoder, R. Johnson, K. Gruver, K. Tope, J. Bourassa, R. Phillips
U.S. Department of Agriculture, Denver Wildlife Research Center, Denver, CO

C. Rossi
U.S. Department of Agriculture Animal Damage Control Center, Seattle, WA

D. Sparling, R. Grove, E. Hall, M. Gustafson, P. Klein
U.S. National Biological Survey, Patuxent Wildlife Research Center, Laurel, MD

W. Eldridge
U.S. Fish and Wildlife Service, Division of Migratory Bird Management, Anchorage, AK

L. Reitsma, B. Steele, S. Burson
New England Institute for Landscape Ecology, Canaan, NH

B. Roebuck, S. Nam
Dartmouth Medical School, Hanover, NH

<u>**Points of Contact:**</u>

W.A. Gossweiler
Director of Public Works
600 Richardson Drive #6500
ATTN: APVR-PW-ENV
Fort Richardson, Alaska 99505
(907)-384-3017
(907)-384-3047 Fax

Charles M. Collins
CRREL
72 Lyme Road
Hanover, NH 03755
(907) 353-5180
(907) 353-5142 Fax

Table of Contents
Volume 1

Table of Contents
Volume 2

I. Executive Summary

INTRODUCTION

This is the fourth annual report (1991-94) describing the results of studies in Eagle River Flats, following the determination in 1990 that waterfowl mortality in this 865-ha estuarine salt marsh artillery range was due to the ingestion of white phosphorus (WP) particles from smoke rounds. This was the first documented case of WP poisoning on a U.S. Army training area, although since then other artillery range training areas have been found to be contaminated with WP. In 1991 and 1992 efforts were focused on determining the nature and extent of WP contamination in ERF and on the monitoring of waterfowl mortality. In 1993 more detailed studies of WP toxicology were initiated by Patuxent, and invertebrate and fish sampling by AEHA was conducted to elucidate aquatic food chain effects. In 1993, the use of radiotelemetry was initiated by Denver Wildlife Research Center to monitor waterfowl movement and mortality.

In 1992 it was determined that although WP has a reputation for being easily oxidized, it is very stable as a solid particle underwater and in saturated sediments. Pilot field treatability studies began in 1993 and were expanded in 1994 to include dredging, barriers, chemical repellants, natural attenuation and pond drainage. Investigations of physical dynamics began in 1992 and continued to the present. Waterfowl census by aerial survey began in 1989 and have continued to the present.

II. SITE CONDITIONS

II-1. Ecological Inventory

Charles H. Racine and Michael Brouillette (CRREL)

Field studies, mapping and evaluation of the terrain (water bodies, vegetation, topography, soils and disturbance) in Eagle River Flats, an 865-ha estuarine salt marsh and artillery impact area on upper Cook Inlet, were conducted in order to better characterize the ERF ecosystem, help evaluate white phosphorus distribution, persistence and ecological risk, and provide a baseline for evaluating and predicting the future effects of remediation. Base maps of ERF showing these terrain features, sampling and study sites were prepared and presented in a Map Atlas appendix to this report.

Twenty-one field transects from 100 to 1500 m long were positioned across the major environmental gradients and sampled at intervals of 20–40 m for vegetation, topography (elevation), soil texture, water bodies and disturbance (craters). The results of this study and air-photo interpretation were used to describe, classify and map into a Geographic Information System (ARCINFO) the derived terrain units. These units were also evaluated in terms of their habitat use, potential to contain and store white phosphorus, and susceptibility to disturbance by remediation measures.

Six types of water bodies (intermittent and permanent ponds, rivers, wet swales, tidal gullies and drainageways). seven large landscape zones and 15 landform–vegetation classes were recognized, described and mapped. Zones are arranged from both the river toward the upland border and from the coastal beach inland. Three zones (mudflat/gully, pond/marsh and interior lowland) account for about 80% of the area of ERF. A diverse range of vegetation types were classified and mapped including barrens, halophytic wet meadows, marsh, brackish pondweed, sedge meadows, sedge bog, marine alga, border scrub–shrub and woodland. The flora of ERF consists of about 60 species of vascular plants, many of which occur in other Cook Inlet salt marshes. Plant species diversity is generally low except on a few higher relict ridges. Bird species use is described for each of 12 habitat classes.

Surface elevations decrease by 0.5–1 m over a distance of about 500–1000 m back from the levees (at about 5.0-m elevation) along Eagle River into the pond/marsh zone at elevations of 4.0–4.6 m. However, bottom elevation of ponds in Area C and Bread Truck (east of Eagle River) is greater (4.7–4.9 m) than to the west of Eagle River (Area A). The lowest elevations occur at the southern end of ERF (Area B), farthest from Cook Inlet. The surface materials contain increasing fractions of clay-sized sediment from the levees into the ponds and marshes. Organic soils overlie the mineral sediments in the border zone adjacent to the uplands.

Ponds and marshes with their bottom elevations below 4.5–4.7 m are permanently flooded-saturated, and therefore the opportunity for natural attenuation of WP is unlikely. Dredging of the permanent ponds and marshes will remove most food items (seeds, invertebrates and pondweed) and create more areas of open water. Changes in water depth and the salinity of the water in the ponds and marshes due to dredging could also change the ability of species to revegetate these areas.

II-2. Physical System Dynamics in Relation to White Phosphorus Transport and Remediation

Daniel E. Lawson, Susan R. Bigl, Lewis E. Hunter, Beth M. Nadeau, Patricia B. Weyrick and John H. Bodette (CRREL)

This study analyzes the physical processes of erosion, sedimentation and sediment transport, the factors controlling their activity, and the physical transport of WP within ERF. Potential physical system responses to natural or anthropogenic remedial measures, and the potential effects of the physical system on proposed remedial measures are also discussed. Our investigations of the physical system over the past three years have significantly improved knowledge of the processes actively changing ERF and determining the flux of sediment and water within the system.

Tidal height fluctuations were measured in 1994 in concert with water level changes in eight major tidal gullies and in the Eagle River where it discharges into ERF. These measurements define the timing and distribution of flood and ebb waters and qualitatively assess the contribution of the Eagle River discharge to flooding. Suspended sediment concentrations were also measured in the Eagle River, gullies draining the ponds and mudflats, and Knik Arm to define the contribution of these sediment sources to pond and mudflat sedimentation. Salinity, temperature, dissolved oxygen (DO), pH and turbidity were measured to assess the contributions of tidal or riverine water masses to flood and ebb cycle white phosphorus (WP) sedimentation, transport and erosion. Hydrologic parameters including drainage pattern, channel gradients, channel cross sections and flow velocity were also analyzed to calculate ebb discharge and sediment and WP particle transport rates, and to model sediment and water flux. Over 200 sediment samples were collected and analyzed for WP.

The results of our studies have shown that the ERF system is extremely complex, with multiple internal parameters that vary daily, seasonally and annually and with long-term external controls. The natural system is governed by a high tidal range, glacial river influences, large sediment influx from two distinct sources, and a subarctic coastal climate. In addition ERF is located within an active earthquake zone that increases the potential for rapid and unpredictable physical changes in the future. The use of ERF as an artillery impact range, has also produced explosion craters, which have caused physical changes to the terrain, hydrology and surface drainage.

Tides

The elevation and duration of tidal inundation affect sedimentation. Tidal flooding of the Bread Truck, C pond, A and Racine Island areas is enhanced by the discharge of the glacially fed Eagle River, with its timing, peak height and duration affected by seasonal peaks in meltwater discharge and precipitation in the river's watershed. In contrast, tidal inundation is related to tide height in gullies closer to the coast. Similarly, the direction and velocity of the wind across ERF preceding and during tidal inundation may either enhance or reduce the height and duration of inundation. Storm-driven water masses in Cook Inlet may have the same effect on flood height in Knik Arm. Limited data indicate ice and snow cover can enhance the height and duration of flooding as well.

A comparison of water level variations at the heads of eight gullies across ERF and in the Eagle River showed a 20- to 40-min delay in the timing of the peak tidal flood height relative to that predicted at Anchorage by tide charts. When the predicted tide height is sufficiently high to flood part or all of ERF, the actual peak elevation exceeds that height. Flood height is generally greater than the Anchorage datum by 0.5 m or more, with the amount dependent on the volume of glacial meltwater in the Eagle River and possibly Knik Arm. The general increase may be caused by the constriction in Knik Arm south of ERF.

Suspended solids

The total suspended solids (TSS), or suspended sediment concentrations, in waters of ERF vary with tidal stage, location, source and season. The glacially fed Eagle River varies seasonally from peak TSS values of 100–700 mg/L between breakup in May and freeze-up in October. Two seasonal highs occurred in 1994, the first occurring in early June during snowmelt runoff and the second in early August during the peak glacial melt season. In contrast, waters of Knik Arm ranged from about 1000 to 2800 mg/L from May to October and appear to be the primary source of new sediment in ERF. A range in TSS values similar to that of

Knik Arm characterized the eight gully sites indicating this casual relationship. During any given tidal cycle, TSS values steadily increased with the flooding tide, but progressively decreased at a slower rate during the ebb. Seasonally, TSS values in gully and Knik Arm waters increased from spring to fall; the cause of this increase is unknown and under study.

Sedimentation

Sedimentation ranges from several mm per year on levees, 10–15 mm on mudflats, and up to 20–40 mm per year in ponds. If the high sedimentation rates measured in ponds are characteristic, natural sedimentation would aid in infilling of dredged areas and may provide a method of burying and thereby naturally avoiding WP ingestion by waterfowl.

Eagle River provides access for tidal waters to inundate the innermost reaches of the Flats. Increases in water level and reduced or halted flow result from tidal damming by incoming flood waters which may lead to localized increases in depositional rates. Preliminary analyses indicate that sedimentation in the northern two-thirds of ERF is tidally dominated, whereas the southern one-third appears to be river-dominated. Sediments deposited by the Eagle River at the head of the Flats where it enters ERF proper has apparently formed an alluvial fan with four radially spreading channels of Eagle River distributing water after entering the tidal flats.

At the exit of Eagle River into Knik Arm, six hours of bathymetric profiling of Knik Arm offshore of ERF revealed the existence of two submarine channels. The primary channel is 100–200 m wide and generally parallels the coast. The secondary channel is located about 1–1.2 km offshore and characterized by erosional features. Large intertidal bars occur north of the Eagle River mouth, and west of the primary channel. These bars, as well as a zone adjacent to the coast line south of the Eagle River mouth, are potential depositional repositories for WP.

Erosion

Erosion and recession rates of headwalls and lateral walls of tidal gullies are also relatively high. Rates ranged from 0.1 to 4.9 m during summer 1992, 0.4 to 6.3 m during winter 1992-93, 0.0 to 9.8 m during summer 1993, 0.0 to 2.3 m in winter 1993-94, and 0.0 to 2.6 m in summer 1994. Gullies are progressively extending into the mudflats toward the pond complexes of the Bread Truck, C, A, D and C/D. Two gully headwalls, one on the western side of Bread Truck and the other near the pond complex between Bread Truck and C ponds, are advancing at a rate sufficient to cause increased drainage of those ponds within the next 15–30 years if the average rates persist. Surveyed longitudinal profiles of tidal gully thalwegs revealed unstable, non-equilibrium gradients that reflect their progressive elongation into the mudflats and ponds by headwall erosion. Headwalls have nearly vertical faces that vary from 1 to 2.5 m in height. Above them, gradients within drainageways range from 0.001 to 0.004 m/m across the mudflats and into the ponds, being slightly lower in slope than within the tidal gullies below the headwall. Tidal current velocity data from three gullies indicate that sediment transport and channel erosion are potentially greatest during the ebb cycle.

White phosphorus transport

There is some area-specific evidence for the movement of white phosphorus via ice-rafted sediments, resuspension in ponds (measured in sediment traps) and ebb tide gully discharge water (captured in plankton nets). Concentrations found to date are too low to indicate actual particle movement, but WP is moving locally in some form. In the case of ice-rafted WP, contaminated pond bottom sediments can freeze onto the ice bottom during its growth and subsequently be uplifted and transported during tidal inundation. Ice and water erosion and transport of WP remain to be quantitatively assessed.

Remediation

Natural attenuation of WP contamination as the result of sedimentation and burial, erosion and pond drainage, abrasion during transport, and other causes needs to be considered. The inherent complexity of this dynamic environment makes it extremely difficult to predict what effects potential remedial measures for white phosphorus (WP) contamination will have on the physical system. Because the physical conditions and processes vary widely across ERF, each specific area slated for WP remediation needs to be evaluated and ranked in terms of the suite of potential remedial measures and their probable effectiveness and success over the short (1–5 years) and long (10–50 years) term. It is equally important that the impact of these treatment methods on the physical system be evaluated before a remedial technology is selected. For example, in some areas dredging may create conditions that will enhance sedimentation and significantly reduce the need for site restoration. In other areas of ERF, dredging may modify the hydrology such that gully erosion increases, thereby altering the drainage system and perhaps extending it into the dredged area. Dredge operations may disturb underlying sediments, thereby increasing their susceptibility to erosion.

Site-specific effects of erosional processes must be considered before remediation is initiated. Erosion, for example, can affect the integrity of measures such as capping by AquaBlock or geotextiles. Both ice and currents are critical mechanisms in this regard. Ponds in which WP contamination is remediated by temporary drainage and drying may subsequently have clean sediments uplifted and removed by ice, thereby exposing WP bearing sediments below. Similarly, areas remediated by removal of WP-bearing sediments may be infilled with WP-bearing sediments that were eroded elsewhere in ERF and then transported and redeposited at the site.

Information needs

A conceptual model of the physical ecosystem and WP fate and transport remains to be developed. Some specific gaps in knowledge of the physical system include very limited data on WP transport and persistence, ground water hydrology of ponds and marshes, environmental controls on WP deposition in the Eagle River and Knik Arm, and the factors, controls and interactions of processes causing long-term morphologic changes that will impact WP remediation.

II-3. Climate and Tides

Richard Haugen (CRREL)

Meteorological elements and tidal inundations are the major driving forces for physical and biological processes within ERF. In May 1994 a meteorological site was installed at ERF next to the EOD pad to provide baseline data for ongoing investigations. Comparisons between ERF and the Anchorage climatic record (Anchorage airport) showed that daily maximum temperatures were about 1°C cooler at ERF and minimum temperatures 2.3°C cooler. A comparison of mean daily air temperatures between the ERF main site at the EOD pad and an ERF coastal meteorologic site showed a 5.3°C difference, showing that air temperature variances within ERF are greater than the ERF/Anchorage differences.

A historical analysis of Anchorage temperature and precipitation from 1917 to the present was done to compare the normalcy of the weather during the ERF project on a monthly basis. The ERF field seasons of 1993 and 1994 can be characterized as normal except that May 1993 was more than one standard deviation warmer and wetter than normal, and August 1994 more than one standard deviation warmer and drier than normal.

A program for the development of tidal tables was obtained from NOAA and adapted to predict past and future periods of tidal inundation of ERF. A table of predicted tides high enough to flood ERF for the months of May through October is given for the period 1994–1997. Additional tables for 1960–2000 were produced for comparisons with the historical climatic record previously mentioned. The purpose is to compare historical time series of tidal inundation, air temperature and precipitation for the ERF area to determine the frequency of extended periods of pond drawdowns and drying soil moisture conditions. Such data are of considerable importance to the fate of white phosphorus in the soil.

III. WP EVALUATION AND CHARACTERIZATION

III-1. White Phosphorus Toxicity and Bioindicators of Exposure in Waterfowl and Raptors

Donald W. Sparling, Robert Grove, Elwood Hill, Mary Gustafson and Patrice Klein (PESC)

During 1994 researchers at the National Biological Service Patuxent Environmental Science Center conducted studies on seven tasks associated with risk assessment and monitoring of white phosphorus (WP) in Eagle River Flats, Fort Richardson, Alaska. These tasks included: 1) identification of biomarkers of WP in waterfowl; 2) preliminary studies on reproductive effects of WP in female mallards; 3) timing of uptake and loss of WP and the onset of pathology in mallards; 4) derivation of LD50 and associated statistics for adult female mallards; 5) analysis of acute toxicity with pelletized WP; 6) examination of secondary toxicity in kestrels fed dosed poultry chicks; and 7) use of semi-permeable membranes (SPMDs) in monitoring WP in water and sediments.

Identification of biomarkers for white phosphorus exposure in birds.

White phosphorus residues can only be measured in living tissues for a few days post exposure. Moreover, sublethal doses of white phosphorus can cause chronic or long-lasting effects. Therefore, identification of other physiological effects of exposure or bioindicators are essential for reliable assessment of risk to waterfowl and other species inhabiting areas contaminated with WP. In an initial study to identify potential biomarkers, mallards were dosed either once or twice with WP dissolved in oil. Before dosing and three days post each dose, a 5-mL sample of blood was taken and sent to a commercial veterinary diagnostic lab to determine changes in specific blood parameters. The blood factors that showed the greatest response to WP included blood urea nitrogen (BUN), BUN/creatinine ratio, lactate dehydrogenase, aspartate aminotransferase/alanine aminotransferase ratio, potassium and glucose. Hematocrit, hemoglobin, chloride, sodium and phosphorus also differed significantly due to treatment. These blood factors reflect the liver and renal damage identified by histopathological examination and hemolysis observed in pen studies. Additional analyses on other blood samples taken in laboratory and field situations are near completion and seem to support the above findings. At this early date, we suggest that reduced hematocrit and hemoglobin levels could be effective, reliable, and relatively simple screening techniques to identify birds that may have been exposed to white phosphorus.

Preliminary Studies on Reproductive Effects of WP in Female Mallards

White phosphorus is a strong reducing agent, is lipid soluble, and appears to affect many physiological processes in mallards. Therefore, it has the potential of reducing reproduction and collecting in egg yolks, where it could affect developing embryos. A pilot study was conducted to determine if repeated handling of adult female mallards alone would impair reproduction or egg laying ability and to find effective dose levels prior to a more complete reproductive study. Four to five female mallards were gavaged with pelletized WP at either 2.6 or 1.3 mg/kg body weight daily for five days. Other groups were either given a placebo of distilled water or left alone except for daily egg collection (control). The placebo and control groups did not differ in number of eggs laid, fertility or hatching success. Thus, we determined that daily handling did not appreciably alter reproduction in these birds. Two of the five females given 2.6 mg WP/kg body weight died within the first five days of treatment; another became lethargic and showed obvious signs of distress. All three surviving birds stopped laying eggs after two doses. One of these birds came back into sporadic lay 11 days after the last dose but did not produce fertile eggs. Four young hatched from these hens but from early eggs that probably escaped exposure to white phosphorus. One embryo had severe teratogenic deformities. At 1.3 mg/kg one hen stopped laying after two doses and the other four birds laid erratically so that the average number of eggs laid was significantly fewer than either the placebo or control birds. Only nine young developed from eggs at the lower dose and only one of these hatched. Three embryos that failed to hatch had teratogenic deformities. Deformities included scoliosis, lordosis, submandibular edema, microphthalmia and spina bifida.

Timing of Uptake and Loss of WP and the Onset of Pathology in Mallards

The uptake and loss of white phosphorus from living tissues is important because of the possibility of secondary toxicity and human health perspectives associated with waterfowl hunting. Obviously the risk of secondary exposure is related to the retention time of WP in tissues. Adult mallards were gavaged with a single dose of pelletized white phosphorus at 1, 2 and 4 mg/kg and then sacrificed at 3, 6, 12, 24, 96 and 240 hr post dose. Birds were necropsied for obvious organ damage and fat, liver, kidney, breast muscle and brain were harvested for residue determinations. Ten of the 12 birds dosed at 4 mg/kg died within 24 hr post dose. The two survivors at this dosage were sacrificed at 240 hr; one appeared healthy and unaffected whereas the other had severe necrosis in approximately half of its liver and trace levels of WP in its fat. We surmise that the healthy bird had probably orally voided the pellet shortly after dosing. At 1 and 2 mg/kg, white phosphorus was assimilated within the first three hours after exposure, reached peak levels in fat within 6–12 hr post dose, and was at or near detection limits within 48 hr. Liver levels increased during the first three hours but rapidly dropped to detection levels by 24 hr post dose. Muscle and kidney levels were very low and essentially gone within 12 hr post dose. No WP was detected in brain tissue. Fatty livers appeared in a few birds as early as three hours post dose at the 2 mg/kg level.

Adult Female Mallard Acute Toxicity

Work conducted during 1993 allowed us to determine that the LD50 of WP dissolved in oil for adult males as 6.4 mg/kg and that there was no difference between adult males and juvenile birds of either sex. However, adult females appeared to be much less sensitive to WP than the other age-sex classes and we were unable to confirm an LD50 for this group. In 1994 we repeated our acute toxicity experiment with adult females at the same time of year (late July–early August) and breeding condition (post laying) as in 1993. We determined that the LD50 for adult females was 6.8 mg/kg, which was not statistically different from that for adult males. However, adult females have a much shallower dose- response curve than adult males ($P < 0.0001$). This shallower slope makes predictions of mortality at specific dose levels less certain and also changes the risk assessment characteristics for adult females compared to males.

Confirmation of Acute Toxicity and Lowest Observable Effects Level with Pelletized White Phosphorus

Much of the work on acute toxicity of other compounds suspends the compound in a carrier such as water or corn oil. Our initial experiments used the same approach for comparability but waterfowl at Eagle River Flats are exposed to pelletized WP. Thus we conducted a small test to compare the acute toxicity of pelletized WP to that dissolved in oil. Fourteen male mallards were given a single dose of WP at 6.5 mg/kg. Twelve died, which was greater than the expected number of seven ($P < 0.05$). Thus pelletized white phosphorus is more toxic to adult male mallards than is white phosphorus dissolved in oil. Based on other studies that were conducted in 1994, we estimate that the LD50 for pelletized WP is between 3 and 4 mg/kg. To determine the subacute effects of pelletized white phosphorus we dosed 10 males at each of two levels, 2.4 and 3.4 mg/kg daily for 10 days. At 2.4 mg/kg three mallards died but not until the eighth dose. One bird that was debilitated for three days post the last dose had a pellet lodged in its gizzard, indicating that birds can hold pelletized WP for several days post ingestion. Six of 10 mallards at 3.4 mg/kg died during the study, the first after two doses. One survivor also had a smoking gizzard four days past the last exposure. Pathological damage was extensive in both groups of birds and included fatty liver degeneration, liver necrosis, kidney damage, decreased hematocrit and hemoglobin, decreased number of lymphocytes and elevated heterophil counts. Our lowest dose was above the lowest observable effects level (LOEL) for repeated doses because 1.3 mg/kg can alter reproduction in females, but we estimate that the LOEL for single doses is approximately 1–2 mg/kg.

Secondary Toxicity of WP in American Kestrels Fed Treated Chicks

To assess the potential for secondary toxicity, we dosed 10-day-old poultry chicks with three pellets of white phosphorus over a 24-hr period. These chicks were then euthanized and frozen. Later we divided the chicks into two groups. One group (NoGut) had the upper digestive system (crop, proventriculus and gizzard) removed; this dissection was to remove any intact pellet from the digestive system to determine if predators can be intoxicated by tissue levels alone. The other group (Pell) was kept intact and a 1.1-mg pellet of WP was surgically placed into their crop; this simulated a prey item with undigested WP in its gizzard or crop. A third group of chicks were undosed controls. These chicks were subsequently fed to American kestrels for seven days when 50% of the kestrels on the Pell diet had died. Tissue levels in chicks were similar to those found in waterfowl and the 1.1-mg implanted pellet represented a dose of 6.8–10.8 mg/kg body weight in the kestrels, similar to that potentially encountered by eagles feeding on gizzards of dead or dying waterfowl. Eight of 15 kestrels on the Pell diet died during the study, the first after only two days. Three of 15 kestrels on NoGut diet also died but only on the fourth (1) and tenth (2) days of treatment. Pathological effects were observed among survivors in both groups compared to controls. Significant differences occurred in hematocrit, weight loss, liver/body ratio and hemoglobin. WP was found in the tissues of kestrels from both the NoGut and Pell treatments. The study showed that predators are at risk of intoxication when they eat either the carcass or gizzards of moribund and dead waterfowl.

Development of Semi-Permeable Membrane Device (SPMD) to Evaluate White Phosphorus Presence in Water and Sediment

Preliminary steps have been completed in determining if SPMDs can be used to monitor water and sediments for the presence of WP. A problem occurs in that the vapor pressure difference between WP and the solvent isooctane is only 1.1×10^3, which is too low for reliable extraction. Therefore, n-pentane, which has a vapor pressure differential of 1.2×10^4, is being tested instead.

III-2. Toxicological Properties of WP: Comparison of WP Particle Sizes on Acute Toxicity and the Biotransfer of White Phosphorus from Hen to Eggs

B.D. Roebuck and Sae-Im Nam (Dartmouth College)

To date, all of the published data on the toxicity of WP in ducks have been based on WP dissolved in oil or in tissues. The present studies were therefore undertaken to assess if toxicity of WP differed between WP dissolved in an edible oil and particles of size classes representative of the particles found in the sediments at ERF. The distribution of WP in the GI tract was also determined in both lab and wild birds to assess the risk of WP to predators. Detailed observations were also made to identify a time point that sick birds could be therapeutically treated. Cholinesterase activity was also measured to determine another mode of treatment. Studies were also undertaken in egg-laying chickens to further explore the biological fate of absorbed WP.

Toxicity from dissolved and particulate WP was very similar at a dose of 12 mg/kg. The time of death in minutes (mean ± std. dev.) was 250 ± 110, 300 ± 100, and 230 ± 60 for the dissolved WP, small particle and large particle groups, respectively. The time of death for all three treatments were not statistically different from each other. In laboratory ducks, the quantity of WP in their digestive tracts varied between treatment groups. The highest quantity of unabsorbed WP (19% of given dose) was in the GI tract of small particle dosed ducks. The dissolved WP was not appreciably retained by the gizzard and reached lower portions of the digestive tract. Ducks from DWRC and ERF all had varying levels of WP distributed in their GI tract, The short latent period between the first signs of intoxication and convulsion argues against effective treatment of sick birds. And finally, the lack of cholinesterase inhibition indicates that antidotes for anticholinesterase poisoning would not be effective.

IV. DISTRIBUTION AND CONCENTRATION OF WHITE PHOSPHORUS IN EAGLE RIVER FLATS

IV-1. Analysis of the Eagle River Flats White Phosphorus Concentration Database

Charles H. Racine (CRREL)

The purpose of this study was to maintain, update and analyze the WP concentration database for ERF. Maps showing the location and concentrations of samples are presented in a Map Atlas appendix to this report. Over 1900 WP concentration measurements have been made on sediment and water samples from ERF since 1991. During 1994 about 500 sediment and 90 water samples were collected and analyzed for WP. Sampling in 1994 was concentrated in tidal gullies, experimental pens, and remediation test sites. AEHA collected samples at a wide range of ponded areas and also sampled gullies and the Eagle River in conjunction with invertebrate sampling.

Of the 1845 sediment samples that have been collected from ERF, no WP was detectable in about 65% of the samples. Of the positive samples only 15% had concentrations above 1 µg/g; therefore, where WP contamination occurs in ERF pond sediments, it takes the form of very low WP concentrations (<1µg/g) over fairly extensive pond bottom areas. These areas are punctuated with small localized "hot spots" of much higher concentrations (>1 µg/g).

No new areas of WP contamination were identified in 1994. One exception was the finding in November (following a flood tide) of low levels of WP in pond sediments adhering to the bottom of rafted ice blocks. There is still little or no evidence for WP contamination in sediments from mudflats and in tidal gullies. In 1994 high levels of WP continued to be found in pond bottom sediments in Area C, on Racine Island and in the Bread Truck Pond. Only low levels of WP contamination have been found in Area A ponds. Although a number of additional samples were collected in Areas B and D during 1994, no WP was found. The distribution of WP in ERF is closely correlated with the distribution of high crater density indicative of past WP input.

When evaluating the degree of WP contamination of a site, both the percent positive samples, the maximum concentration value and the geometric mean are useful. However, analysis of WP concentration data sets from a range of different sites and scales shows very high levels of variability making the use of parametric statistics difficult. Normalization of the data using natural log transformations and calculation of the geometric mean is useful, but a new sampling technique that would reduce the heterogeneity and better represent the WP concentration at a site is needed. The use of nonparametric statistics for WP concentration data may be more appropriate. One method to reduce variability involved stirring the water above the sediment and collecting a water-sediment slurry for analysis. This method was tried with marginal success.

Because of the high variability in WP concentrations at a site, it may be difficult or impossible to use WP sediment concentration data in risk assessments and for evaluating the effectiveness of remediation. Selective sampling of known hot spots before and after remediation may be useful. The use of sentinel or penned ducks combined with mortality measures (by telemetry and transect counts) after remediation may be important to evaluate the success.

Correlations between WP sediment concentrations, the presence of detectable WP particles and mortality rates for mallard ducks placed in six experimental pens were fairly reasonable. It is likely that only the restricted "hot spots" with higher concentrations (1–3000 µg/g) contain particles sufficiently large (greater than 0.5 mm) to be selected by and cause acute toxicity to a feeding duck. Only 15% of the WP-positive sediment samples collected in ERF show concentrations above 1 µg/g. The fact that a relatively small percentage of the waterfowl that feed in ERF probably die from WP poisoning also supports the "hot spot" theory and agrees with our finding that less than 15% of all WP-positive sediment samples have concentrations over 1 µg/g. Only in sediment samples with concentrations above this level have we been able to find identifiable particles of WP. However, mallards died when placed in pens from which nearly 100% of samples had detectable concentrations of WP, all of which were less than 1 µg/g.

V. RISK ASSESSMENT AND FOOD CHAIN EFFECTS

V-1. Waterbird Utilization of Eagle River Flats, April–October 1994
William Eldridge (FWS)

The objective of the 1994 aerial waterbird survey was similar to that of previous aerial surveys of ERF, initiated in 1988: to monitor waterbird abundance and distribution on ERF during spring, summer and fall. A total of 43 aerial surveys were conducted from April through October 1994, Flights were made generally twice per week during spring and fall and once per week during summer.

V-2. Waterfowl Use and Mortality at Eagle River Flats
Leonard R. Reitsma and Ben B. Steele (NEILE)

The main objective of the waterfowl mortality work in 1994 was to continue measuring mortality with the standardized method established in 1991 and further revised in 1992. In addition, habitat use studies were conducted for input into the IRAM (Integrated Risk Assessment Model) described below. Photo-identifications of scavenger species which remove WP-poisoned carcasses from ERF were also conducted.

Carcasses were counted on transects in Areas A, C, the Bread Truck Pond and Racine Island during the spring and fall migration periods. We also counted feather piles on transects in the bordering woods in the spring. These feather piles represent carcasses removed from the Flats by scavengers (mostly eagles). Mortality was calibrated by daily censuses to quantify use of ERF by migrating waterfowl over the same period. These data were used in an ANCOVA (Analysis of Covariance) to analyze for significant differences in mortality between years.

The mortality rate in the spring of 1994 was significantly lower than in the springs of 1993 or 1992. The mortality rate in fall 1994 remained lower (as in fall 1993) than in fall 1992. Reasons for these differences are discussed.

Waterfowl habitat use was quantified by conducting simultaneous observations of waterfowl behavior from two to four locations in spring and fall. These observational data can be used to assess habitat preferences and to calculate risk using the Integrated Risk Assessment Model described below.

Preliminary photographs at carcass-baited trip mechanisms wired to cameras in the woodland bordering ERF indicate that coyotes and northern harriers may be exposed to WP through secondary contact with duck parts left in the woods by predators and scavengers. The severity of this contact was not determined.

V-3. Movements, Distribution and Relative Risk of Waterfowl, Bald Eagles and Dowitchers Using Eagle River Flats

J.L. Cummings, C.A. Yoder, R.E. Johnson, P.A. Pochop, K.S. Gruver, J.E. Davis, Jr., K.L. Tope, J.B. Bourassa and R.L. Phillips (DWRC)

We determined spatial distribution, movements, turnover rate and mortality of waterfowl, bald eagles and dowitchers using ERF, during spring migration, April–May 1994. Thirty-four ducks, 20 dowitchers and 10 bald eagles were captured on ERF; all birds were fitted with radio transmitters. This included 27 mallards, 4 green-winged teal and 1 northern pintail. Of the 10 eagles, 3 were fitted with satellite transmitters. All eagle transmitters are expected to last 17 (standard) to 24 months (satellite). Mallards and teal averaged 6.8 days (range: 1–17 days) on the Flats. Average daily turnover for waterfowl was about 5%. Mortality of the transmitter-fitted waterfowl during the spring migration period was about 12%. Mallards and green-winged teal tended to concentrate in areas C, C/D and D. Hazing resulted in waterfowl movement into areas B and D and off the Flats.

Bald eagles spent an average of 2.9 days on the Flats. Most of the telemetry contacts with eagles were in the wooded area bordering ERF. Eagles fitted with satellite transmitters are currently (December 1994) near Kodiak Island and Cordova, Alaska. No eagle mortality was documented; however, a mallard transmitter was found in an eagle nest on ERF. Dowitchers spent an average of 6.8 days on the Flats and mainly foraged in highly contaminated areas without any mortality.

Recommended are to integrate telemetry data into the Integrated Risk Assessment Model; assess future remediation actions with telemetry studies; minimize research efforts on shorebirds; and continue to monitor those bald eagles breeding adjacent to ERF.

V-4. Evaluation of White Phosphorus Effects on the Aquatic Ecosystem

Carl A. Bouwkamp (AEHA)

The purpose of these studies was 1) to determine if WP at ERF is having an adverse impact on the aquatic biota or bioaccumulating in the aquatic food chain and 2) to determine through a laboratory invertebrate bioassay, a no-observable-effect level (NOEL) concentration for WP in sediment. Sediments and invertebrates from pond bottoms and gullies were collected at 23 sites in May and 39 sites in August. There is little evidence that the macroinvertebrate populations were affected at the highly contaminated sites based on the diversity, number of species, or number of organisms per unit area. No WP was detected in the invertebrates and stickleback fish living in the ponded areas of ERF except for low levels in three fish samples and one invertebrate sample in the fall 1994 study. The data from these studies indicate that a WP cleanup level would not be driven by effects on benthic macroinvertebrates or bioaccumulation in fish tissue.

V-5. Integrated Risk Assessment Model (IRAM) for Determining White Phosphorus Encounter Rate by Waterfowl

L. Clark and J. Cummings (DWRC); C. Racine (CRREL); B. Steele and L. Reitsma (NEILE)

The objective of this study was to develop a simple method for risk assessment using WP encounter rate by dabbling ducks feeding in ERF. The general model, M = cFW, relates the probability of mortality M to F, the proportion of time a duck spends feeding, and W, the probability of encountering a WP particle (c is a proportionality constant relating F and W). Using data from telemetry studies in which about 10% of the transmitter-collared ducks died (M) and feeding effort data for mallards indicating that 80% of their time is spent feeding. Using c = 1 and solving for W = M/Fc, the marsh-wide probability of encountering a lethal dose of WP is predicted to be 0.125. This value is in line with the percentage of all pond and marsh sediment samples having concentrations greater than 1 µg/g (the level at which we can find actual WP particles). This model still requires refinement to account for differential use of specific habitats or site-specific feeding particularly since remediation would be site-specific. Therefore another model is proposed which relates the probability of encountering a lethal WP particle to the particles per unit mass of sediment, the amount of time spent feeding, the duck's rate of feeding and its efficiency in recovering particles of a certain size. Literature-based values for feeding rate and efficiency are available, but refinement of the particle size distribution per unit mass of sediment is still needed on a site-specific basis.

VI. TREATABILITY STUDIES

VI-1. Chemical Hazing of Free-Ranging Ducks in Eagle River Flats: Field Evaluation of Rejex-It™ Wl-05

L. Clark and J. Cummings (DWRC)

Continued field testing of a chemical waterfowl repellent was carried out in ERF during 1994. Because water levels in the ERF were low and decreased during August 1994. waterfowl activity was concentrated into a few ponds. These conditions were ideal for the proposed chemical repellent treatment. Sufficient methyl anthranilate beads were applied to test areas in C pond to provide adequate coverage of the sediment. The detailed behavioral data suggest that ducks readily recognized boundaries of treated areas and entered such areas only as a means of transit from one untreated site to another. There may be a minimum area effect for an effective treatment. A treatment of less than 0.1 ha did not appear to repel ducks from that area. As the cumulative total area of a treatment increased, the number of entries into the area decreased. These data are suggestive of an overall area repellent effect. We conclude that treatment of the sediment with encapsulated repellent may be a viable strategy to prevent ducks from using WP-contaminated areas. If used as a hazing tool on Eagle River Flats, methyl anthranilate beads should be employed over contaminated areas greater than 900 m^2 at an application rate of 0.017-kg active ingredient per square meter.

The water column data on methyl anthranilate release show that loss of the repellent material is constant over time. However, in the field the data suggest a high level of integrity between 0 and 5 days, whereupon there is catastrophic failure of the bead, resulting in significant loss of methyl anthranilate. Given the organic nature of the shell (gel alginate), we suggest that the integrity of the bead is attacked by microbes as a nutrient source. The field failure rate for all beads tested to date is about five days and cannot generally be improved upon so long as a biodegradable gel alginate capsule is used.

VI-2. Hazing
Corey Rossi (USDA-APHIS-ADC)

During parts of May, September, and October of 1994, Animal Damage Control (ADC) continued efforts to keep migratory waterfowl from being poisoned by white phosphorous in ERF. The work involved the use of a variety of hazing methods including propane cannons, scarecrows, mylar tape, as well as eagle effigies and electronic guards and on-site personnel with shotguns and skyrockets. Activities were confined to discrete, limited areas within ERF, with other less-contaminated areas remaining as undisturbed sanctuaries.

In spite of a number of deviations from the norm in 1994, ADC's hazing operation was quite successful. NEILE's mortality data indicate low waterfowl mortality during active hazing operations. In one case waterfowl began using a unhazed contaminated area and ADC hazing operations were immediately implemented there. The effective protection of waterfowl was further enhanced by a contingency provision in the 1994 proposal which allowed ADC's operations to continue until all of the contaminated areas had frozen over (regardless of the date). This contingency provision will be proposed again for the 1995 season.

VI-3. Evaluation of AquaBlok™ on Contaminated Sediments to Reduce Mortality of Foraging Waterfowl

Patricia A. Pochop, John L. Cummings and Christi A. Yoder (DWRC)

The results of a 1993 pilot study indicated that the AquaBlok™ barrier system could reduce mortality of foraging waterfowl on Eagle River Flats, Alaska. Therefore, a more definitive study was conducted in 1994. Our objectives were to evaluate the longevity of AquaBlok™ when applied to an isolated pond on ERF up to 0.5 ha in size and to measure its effects on waterfowl foraging behavior and mortality. A WP-contaminated test pond on Racine Island was selected and a pen constructed around it. During pretreatment, 23 experimental mallards (*Anas platyrhyncos*) died in a control pen in Area C and 15 died in the pen in the test pond over 10 days; following aerial application of AquaBlok to the test pond, 24 mallards died in the control pen in C Pond and 3 mallards died in the treated pen. During pretreatment, the mallards in the treated pen in the test pond were observed feeding more than those in the control pen in Area C. However, control ducks in Area C were observed feeding more frequently post-treatment than in the AquaBlok-treated pond. Data collected to date indicate that AquaBlok™ shows promise for reducing waterfowl mortality from white phosphorus poisoning on Eagle River Flats, Alaska.

VI-4. Screening Study of Barriers to Prevent Poisoning of Waterfowl

Karen S. Henry (CRREL)

The objective of the study was to evaluate the potential of four geosynthetic barriers to prevent the movement of WP from beneath the barrier to above it. Emphasis was on the retention of particles larger than 0.15 or 0.25 mm in diameter. A field test in Area C pond involved the establishment of five test circles (A, B, C, D and a control without any geosynthetic) 2.4 m in diameter constructed with a clear plastic Lexan barricade (to prevent mixing of water on the inside and outside of the barrier). The bottoms of three circular plots were covered by a geocomposite (consisting of a needle-punched polyester geotextile approximately 540 gm/m^2, with an apparent opening size of 0.149 mm) overlain by a drainage matrix material (geomesh) consisting of an nylon entangled mesh. The geotextile had 8-cm-diameter holes cut into it, 0.3 m on center to allow for the venting of gas. In one of these three test cells, an 8-cm-thick bentonite layer, provided by the Denver Wildlife Research Center, was placed on top of the geocomposite. A 10-cm gravel fill layer, provided by Ft. Richardson, was placed on top of the geosynthetic in a second circle. No gravel or bentonite layer was placed over the third test cell geocomposite. A biodegradable woven coir (a fiber made from coconut husks) mat was used to cover the ground surface of the fourth test cell.

Disturbance of the barriers were accomplished by vigorous stirring of the water with a canoe paddle and by dynamic loading of the barrier by dropping a mass onto it to simulate a moose walk. The responses measured were amounts of sediment resuspended during the test and percent of the resuspended sediment particles that were larger than 0.15 mm and that were larger than 0.25 mm. The results showed that the barriers reduced the amount of sediment resuspended by about 30% or more. The sediment that moved across the barriers contained less than 3% by weight of particles larger than 0.15 mm in diameter. The barrier consisting of geocomposite covered with 10 cm of gravel was most effective. None of the barriers tested were damaged by loading tests that simulated a moose walk.

VI-5. Investigation of Natural Size Reduction of White Phosphorus Particles in Eagle River Flats Sediments

Marianne E. Walsh and Charles M. Collins (CRREL)

Remediation of sediments at Eagle River Flats, a salt marsh contaminated with solid particles of white phosphorus (WP), may require severe alterations of the wetland by dredging, draining, or covering. However, some sediments may undergo WP decontamination naturally in areas that are seasonally subaerially exposed and where sufficient drying of the sediment occurs. The persistence and attenuation of millimeter-size white phosphorus particles was studied by laboratory and field experiments.

In laboratory experiments where WP particles were incubated under constant moisture contents (degree of saturation = 0.45, 0.64, 0.82, 1 or >1) and temperatures (4, 15 or 20°C), WP particles were persistent at moisture contents at or above saturation. Laboratory-constructed WP particles incubated well below saturation (saturation level = 0.45 or 0.64) were lost rapidly (24 hr) at 20°C, within 30 days at 15°C, and persisted over the time interval tested (approximately 60 days) at 4°C. For samples incubated slightly below saturation (saturation level = 0.82) results were variable, with significant loss in some samples and no change in other samples.

In field experiments on ERF WP particles were incubated at 5-cm depth in salt marsh sediments at 10 monitoring sites ranging from permanently flooded ponds to intermittently flooded ponds to unflooded mudflat and levee sites. WP particles were persistent in the permanently flooded area, but there was loss of WP in areas with unsaturated exposed sediments. Unsaturated conditions were detected down to 30 cm at monitoring sites on the river levee and mudflat and two intermittent pond sites, indicating that loss of WP is possible at depth. However, at depth, loss is likely to be slower due to consolidation, lower temperatures and longer periods of saturation.

Resampling of an intermittent pond WP-contaminated sites, identified and sampled in previous years, also showed loss of WP after the area was subaerially exposed in 1994.

Based on the above results, initial remediation efforts involving active manipulation of the site should be restricted to contaminated permanent ponded areas. At intermittent pond sites where natural attenuation can occur WP levels should be monitored for continued loss of WP.

VI-6. Pond Draining Treatability Study

Charles M. Collins (CRREL)

Work by M.E. Walsh in this report has shown that WP contamination in intermittently flooded pond bottom sediments will also begin to sublime *in situ* if the sediments are subaerially exposed long enough for the sediment to dry below saturation. Whether the WP particles will disappear and how fast will depend on how long the sediments remain unsaturated and what the average soil temperature is. Isolated ponds that are contaminated with WP may not normally become dry enough to expose the contaminated pond bottom sediments or expose them long enough to become unsaturated. Therefore, artificially draining the pond, either temporarily or permanently, would expose much of the WP-contaminated bottom sediment, thus possibly allowing for the in situ sublimation of WP particles.

In this study the potential for draining a contaminated pond to a level where natural attenuation of WP could occur were investigated. The study was carried out in the Bread Truck (BT) pond. Four sites were instrumented to monitor pond levels, sediment moisture and temperature along a transect from a deeper, permanently flooded pond area, through the shallower, intermittently flooded area. A survey of the marsh area to the east of BT pond showed that there was no direct connection between BT pond and the C/D marsh-pond complex in the form of a channel or drainageway that would allow direct flow between the two areas. Site elevations ranged from 4.80 to 4.90 m.

A siphon system consisting of 165 m of 6.1-cm (4-in.) ID rigid PVC plastic pipe was installed from the Bread Truck (BT) pond to a tidal gully north of the pond. The siphon was filled and started on 25 June following the last flooding high tide. The pond level started dropping as water flowed out through the gully as well as through the siphon.

Even though large areas of pond bottom sediment were subaerially exposed, they did not dry sufficiently to allow dissipation of any WP contamination. Maximum soil temperatures at the 5-cm depths were 25°C for both sites, with an average temperature of 16°C. The siphon lowered the pond water level faster than natural draining and evaporation alone, but it was slow. However, it probably did not lower the pond level below that which it would have attained without the siphon. The soil moisture sensors at all depths at both sites did not change during the summer, indicating that the sediment remained saturated throughout the period.

VI-7. Dredging as a Remediation Strategy for White-Phosphorus-Contaminated Sediments at Eagle River Flats, Alaska

Michael R. Walsh, Edwin J. Chamberlain and Donald E. Garfield (CRREL)

Investigations into the fate and persistence of white phosphorus (WP) at Eagle River Flats, Alaska, indicate that although natural attenuation is occurring in areas where intermittent drying takes place, permanently flooded areas are retaining lethal amounts of the chemical. Several remediation strategies for these persistent areas were initiated during the 1994 field season, covering a range of methodologies, including covering contaminated areas, siphoning small permanently ponded areas, and dredging larger permanent ponds. This project covers the preparations and initiation of the dredging remediation operation.

Initial investigations centered on the feasibility of dredging in an active impact area. Discussions with several small dredge manufacturers indicated that a remotely controlled dredge configured to minimize damage in the case of the detonation of an unexploded round would be feasible. A list of technical specifications was developed and sent to the USARAK Contracting Office to be included in the RFQ for a dredge system lease. CRREL engineers then worked with the Contracting Officer in bid evaluation. The contract was awarded to Chem-Track of Anchorage, AK.

Design of the dredge spoils retention basin was a major task in the overall project. The target site, the EOD Pad, is a Solid Waste Management Unit within a RCRA site. As such, much site characterization work was required by the Restoration Program Managers before approval was given for site use. Extensive testing and design work, done in association with the Alaska District, Corps of Engineers, was required. Site characterization and extensive testing was conducted by CRREL engineers. The design work was carried out by District engineers using data gathered from the testing. A 0.8-ha retention basin with 2 m berms was designed. The structure is lined with a peaty-silt soil, which reduces conductivity to $\approx 1 \times 10^{-6}$ cm/s, below the 1×10^{-5} cm/s threshold. A drop inlet structure is located at one corner of the structure for decanting supernatant through a weir and silt fence. Two concrete pads are constructed within the basin for spoils line outfall to prevent erosion of the basin liner. The basin will be reusable with the removal of the treated spoils. Instrumentation was installed in the basin to monitor temperatures, water level and soil moisture. A tap was installed in the spoils line adjacent to the basin for spoils sampling.

Due to procurement delays, equipment modifications dictated by the Safety Plan, and the incomplete state of the equipment on delivery, actual dredging did not commence until mid-October. Due to problems with some of the equipment modifications and the onset of winter, only about two hours of actual dredging over a two-day span was conducted during October 1994. Two samples were taken from the spoils line, one of which was highly contaminated with WP (2.7μg/g). Due to the short amount of operational time in the 1994 field season, a judgment as to the feasibility of dredging cannot be made. However, the ability of the dredging system to remove WP-contaminated sediments has been demonstrated.